Copy No: 10

Background noise levels in the area of the Gully, Laurentian Channel and Sable Bank

Francine Desharnais
Nicole E. B. Collison

Prepared for.
Fisheries and Oceans Canada
Oceans and Coastal Management Division
Bedford Institute of Oceanography
P.O. Box 1006, Mail Stn. B500
Dartmouth, Nova Scotia
B2Y 4A2

Defence Research Establishment Atlantic
DREA ECR 2001-028
April 2001

Author

Francine Deshaies

Approved by

J.S. Kennedy

Section Head/ Underwater Acoustics

Approved for release by

K. Foster

DPS/Chair

The information contained herein has been derived and determined through best practice and adherence to the highest levels of ethical, scientific, and engineering investigative principles. The reported results, their interpretation, and any opinions expressed therein, remain those of the authors and do not represent, or otherwise reflect, any official opinion or position of DND or the Government of Canada.

DRDC shall have a royalty-free right to use and exercise any copyright information for its own internal purposes excluding any commercial use of the information.

© Her Majesty the Queen as represented by the Minister of National Defence, 2001

© Sa majesté la reine, représentée par le ministre de la Défense nationale, 2001

Abstract

The Sable Gully is a submarine canyon at the edge of the continental shelf, east of Sable Island. This region is a potential Maritime Protected Area (MPA) under the Oceans Act. New data sets in the area of Sable Bank, Sable Gully and Laurentian Channel were analyzed to characterize the current ambient noise field in these areas. It was found that the new data sets fit reasonably well with previously published levels for Sable Bank. The directionality of the noise field showed a small increase in the noise levels in the north or northeast direction. This directionality agrees with a previous analysis of several sites on the Scotian Shelf and Grand Banks area.

Résumé

Le passage de l'île de Sable est un canyon sous-marin qui se trouve au bord de la plate-forme continentale, à l'est de d'île de Sable. Cette région peut devenir une zone de protection marine (ZPM) aux termes de la *Loi sur les océans*. Des séries de données obtenues de la région du banc de l'île de Sable, du passage de l'île de Sable et du chenal Laurentien ont été analysées en vue de caractériser le champ sonore ambiant actuel de ces régions. On a trouvé que les nouvelles séries de données correspondent raisonnablement bien avec les niveaux de bruit déjà publiés pour le banc de l'île de Sable. La directionalité du champ sonore a indiqué une légère augmentation des niveaux du bruit dans la direction nord ou nord-est. Cette directionalité correspond à la précédente analyse de plusieurs sites se trouvant sur le plateau Scotian et dans la région des Grands bancs.

102-01377/

This page intentionally left blank.

Executive summary

The Sable Gully is a submarine canyon at the edge of the continental shelf, east of Sable Island. This region is a potential Maritime Protected Area (MPA) under the Oceans Act. New data sets in the area of Sable Bank, Sable Gully and Laurentian Channel were analyzed to characterize the current ambient noise field in these areas.

It was found that the new data sets fit reasonably well within previously published levels for Sable Bank. The levels at 20 Hz are strongly influenced by vocalizing finback whales when they are in the area. From 50 to 100-200 Hz, noise is dominated by shipping. Above 200 Hz, the noise field is dominated by wind stress on the ocean surface.

The directionality of the noise field showed a small increase in the noise levels in the north or northest direction. This directionality agrees with a previous analysis of several sites on the Scotian Shelf and Grand Banks area.

The new data from this work improves the overall knowledge of the background noise field in the Sable Bank, Gully and Laurentian Channel areas, their temporal and spatial fluctuations, and general directionality.

Desharnais, F., Collison, N.E.B. 2001. Background noise levels in the area of the Gully, Laurentian Channel and Sable Bank. ECR 2001-028 Defence Research Establishment Atlantic.

Sommaire

Le passage de l'île de Sable est un canyon sous-marin qui se trouve au bord de la plate-forme continentale, à l'est de d'île de Sable. Cette région peut devenir une zone de protection marine (ZPM) aux termes de la *Loi sur les océans*. Des séries de données obtenues de la région du banc de l'île de Sable, du passage de l'île de Sable et du chenal Laurentien ont été analysées en vue de caractériser le champ sonore ambiant actuel de ces régions.

On a trouvé que les nouvelles séries de données correspondent raisonnablement bien avec les niveaux de bruit déjà publiés pour le banc de l'île de Sable. Les niveaux qui s'élèvent à 20 Hz sont fortement influencés par la vocalisation de baleinoptères lorsque ces derniers se trouvent dans les parages. De 50 à 100-200 Hz, le bruit est principalement provoqué par la navigation. Au-dessus de 200 Hz, le champ sonore est dominé par la tension du vent sur la surface de l'océan.

La directionalité du champ sonore a indiqué une légère augmentation des niveaux du bruit dans la direction nord ou nord-est. Cette directionalité correspond à la précédente analyse de plusieurs sites du plateau Scotian et de la région des Grands bancs.

Les nouvelles données obtenues de la présente étude permettent de mieux connaître de façon globale le champ sonore de fond dans les régions du banc de l'île de Sable, du passage de l'île de Sable et du chenal Laurentien, les fluctuations temporelles et spatiales de ce champ et sa directionalité en général.

Desharnais, F., Collison, N.E.B. 2001. Niveaux de bruit de fond dans les régions du passage de l'île de Sable, du chenal Laurentien et du banc de l'île de Sable. ECR 2001-028 Centre de recherches pour la défense Atlantique.

Table of contents

Abstract i

Résumé i

Executive summary iii

Sommaire iv

Table of contents v

List of figures vii

List of tables viii

Acknowledgements ix

1. Introduction 1

2. New locations 2

3. Data collection procedure 4

4. Data processing 6

4.1 First stage manipulation 6

4.2 Omnidirectional processing 6

4.3 Directional processing 7

4.4 Data quality assessment 8

5. Environmental information 13

6. Omnidirectional noise data 16

6.1 The Gully: Mean noise levels 21

6.2 The Sable Bank: Mean noise levels 23

6.3 The Laurentian Channel: Mean noise levels 25

6.4 Short-term (<1 hour) temporal fluctuations 26

6.5 Spatial fluctuations 28

7. Directional noise data 30

8. The new data in its context 31

9. Summary 34

References 35

List of figures

Figure 1: Site locations: the Gully N, Sable S1, Sable S2, and Gully SE sites are from the 27-May sortie, while Sable N, Gully S, and LC are from the 2-December flight. The small, black-filled circles indicate the wells that were active on 27 May 98; the small, black-filled squares indicate the wells that may have been active on 2 Dec 98 (unconfirmed in the case of Venture, East of Sable Island). 3

Figure 2: Sensor deployment at the Sable N, Gully S, and LC sites. 4

Figure 3: Water temperature profiles at/near each site. 15

Figure 4: Shipping survey for 2 December 1998. 15

Figure 5: Mean noise levels (one-third octave bands) for Gully S (solid line), Gully N (dotted line), and Gully SE (dashed line). 21

Figure 6: Average spectrum (solid line) for the 53D(2) buoy located at Gully S c. The dotted lines represent the mean spectrum ± the estimated standard deviation. 22

Figure 7: Mean noise levels (one-third octave bands) for Sable S1 (solid line), Sable S2 (dotted line), and Sable N (dashed line). 23

Figure 8: Mean noise level (one-third octave bands) for LC 25

Figure 9: Temporal fluctuations for the Gully: Gully S (solid line), Gully N (dotted line), and Gully SE (dashed line). 26

Figure 10: Temporal fluctuations for the Sable Bank: Sable S1 (solid line), Sable S2 (dotted line), and Sable N (dashed line). 27

Figure 11: Temporal fluctuations for the Laurentian Channel. 27

Figure 12: Spatial fluctuations for the 2-December sites: Sable N (solid line), Gully S (dotted line), and LC (dashed line) 29

Figure 13: Beam direction as a function of percent occurrence of maximum (solid lines) or minimum (dotted lines) noise levels for one-third octave frequency bands centered on (a) 63 Hz and (b) 200 Hz. The black lines denote percentages using the 13 buoys from the May and Dec. 1998 data, while the red lines provide a comparison of percentages from a similar study using 138 buoys from Dec. 1995 to Dec 1996. 30

Figure 14. Overview of the range of ambient noise levels versus frequency from [2]. The solid lines and small dots with overlaid standard deviations represents the range of measurements obtained from the EC-SWAN data set [2]; the large filled and unfilled squares, circles, diamonds, upward and downward triangles represent the data sets introduced in Figs. 5, 7 and 8. 32

Figure 15. The solid lines and small dots represents the measurements from [15] and [16]; the diamonds represent the data from Fig. 8. 33

List of tables

Table 1. Deployment dates, locations and descriptor codes for the 1998 sites. 2

Table 2. Acoustic sensor description. 5

Table 3. Magnetic declinations for the 1998 sites. 7

Table 4. Bad records for Sable N (total of 144 30-second records) 9

Table 5. Bad records for Gully S (total of 153 30-second records) 10

Table 6. Bad records for LC (total of 149 30-second records) 11

Table 7. Bad records for 27-May sites (total of 240 30-second records) 12

Table 8. Wind speed and direction, sea state and significant wave height at each site. 13

Table 9. Oil well information from [3]. "A" indicates active wells, "NA" indicates non-active wells. 14

Table 10. Mean noise levels (dB re 1μPa^2/Hz) and standard deviations (dB) for the representative buoy of each apex at Sable N. 17

Table 11. Mean noise levels (dB re 1μPa^2/Hz) and standard deviations (dB) for the representative buoy of each apex at Gully S. 18

Table 12. Mean noise levels (dB re 1μPa^2/Hz) and standard deviations (dB) for the representative buoy of each apex at LC. 19

Table 13. Mean noise levels (dB re 1μPa^2/Hz) and standard deviations (dB) for the 4 buoys of the 27-May flight. 20

Acknowledgements

The authors would like to acknowledge 14 Wing Greenwood and the Maritime Proving & Evaluation Unit for conducting the data collection flights. From DREA, Mark Hazen helped with the coordination with MP&EU for the December flight, Maj. Mark Labrecque did the first-stage manipulation of this data set, Vance Crowe and Jim Theriault, set up the May flight, and Brian Maranda and Ian Fraser provided useful insights to the analysis. We would also like to thank William Richards, Regional Climatologist with the Meteorological Service of Canada, for providing the wind estimates for the May flight. Phil N. Moir of the Geological Survey of Canada (Atlantic) provided us with oil well activity information for the dates of both flights.

1. Introduction

The Sable Gully is a submarine canyon at the edge of the continental shelf, east of Sable Island. This region is a potential Maritime Protected Area (MPA) under the Oceans Act. In view of expanded activities proposed by the oil industry in the vicinity of the Gully, it has become increasingly important to investigate the background acoustic field in the area surrounding the Gully. A better knowledge of current noise levels will simplify monitoring potential changes in the future.

An initial study of the background noise field around Sable Bank was completed by the Defence Research Establishment Atlantic (DREA) in 1999 under contract for LGL Environmental Research Associates [1]. A compilation of all noise data collected and analyzed by DREA was produced as part of this study, and the results were presented at the Acoustics Week in Canada meeting in October 1999 [2]. Other data sets for the area of Sable Bank, the Gully, and the Laurentian Channel were collected in 1998, but were not processed at that time.

This report presents the results from processing these 1998 data sets. Sections 2 and 3 provide a general description of the site locations and the data collection procedures, respectively. Processing procedures are described in Sec. 4, and environmental information is provided in Sec. 5. Results are presented in terms of average noise levels, statistical fluctuations, and general directionality findings in Sec. 6 and 7. In Sec. 8, these data are then merged with other previously analyzed data sets to improve the overall knowledge of the background noise field in the Sable Bank, Gully area and Laurentian Channel. Finally, the report is summarized in Sec. 9.

2. New locations

Acoustic noise data were processed for seven new sites, as listed in Table 1, and shown in Fig. 1. Table 1 includes a site descriptor code that will be used to identify each site throughout this report. Three of the new sites are located near/in the Gully, three are on Sable Bank, and one is in the Laurentian Channel. The 3 sites visited on 2-December are each split into 3 sub-sites, depicted by the squares, triangles and diamonds in Fig.1. These sub-sites are referred to as a, b, and c, and they are further explained in Sec. 3. Figure 1 also includes oil wells that may have been active on 27 May 1998 (small black-filled circles) or 2 December 1998 (small black-filled squares) [3].

Table 1. Deployment dates, locations and descriptor codes for the 1998 sites.

DATE	DEPLOYMENT TIME (UTC)	SITE DESCRIPTOR	POSITION	NUMBER OF SONOBUOYS
27 May 1998	12 10	Gully N	44°10'N 59°W	1
27 May 1998	12 39	Sable S2	43°33'N 59°40'W	1
27 May 1998	12 40	Sable S1	43°41'N 59°40'W	1
27 May 1998	12 54	Gully SE	43°20'N 58°30'W	1
2 December 1998	17.09	Sable N a	44°09.9'N 59°59.7'W	3
2 December 1998	17 10	Sable N b	44°01.2'N 59°52.8'W	3
2 December 1998	17 12	Sable N c	44°01.3'N 60°06.7'W	3
2 December 1998	18 33	Gully S a	44°06.5'N 58°56.7'W	3
2 December 1998	18 35	Gully S b	43°55.9'N 58°52.2'W	3
2 December 1998	18 37	Gully S c	43°55.9'N 59°06.3'W	3
2 December 1998	20 20	LC a	45°35.0'N 57°13.8'W	3
2 December 1998	20 11	LC c	45°26.3'N 57°21.7'W	3
2 December 1998	20 15	LC b	45°26.4'N 57°07.6'W	3

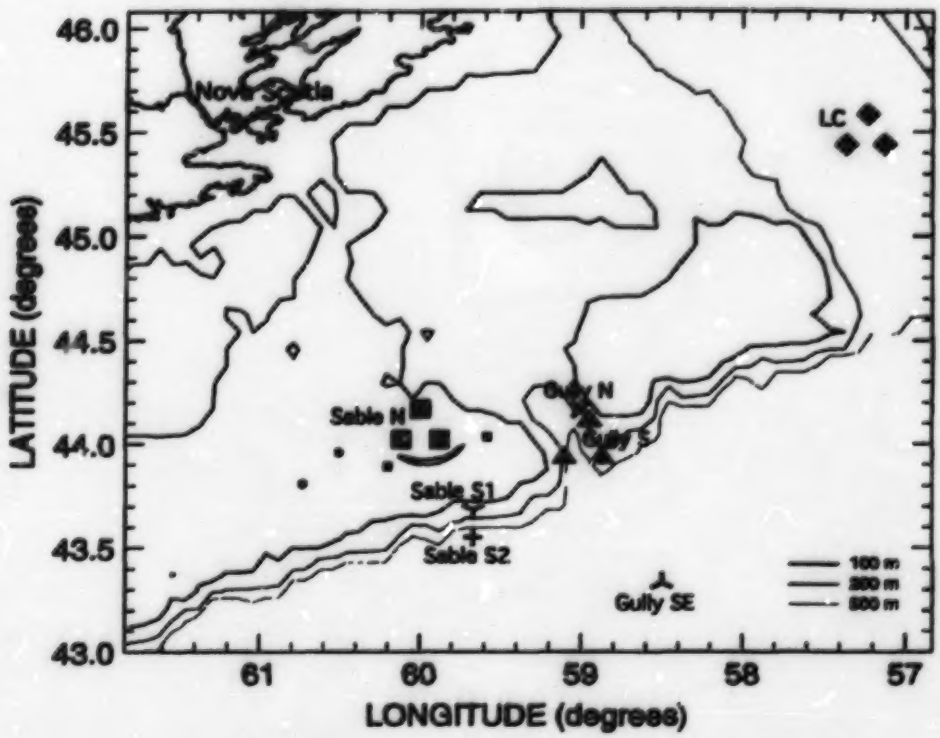

Figure 1: *Site locations: the Gully N, Sable S1, Sable S2, and Gully SE sites are from the 27-May sortie, while Sable N, Gully S, and LC are from the 3-December flight. The small, black-filled circles indicate the wells that were active on 27 May 98; the small, black-filled squares indicate the wells that may have been active on 2 Dec 98 (unconfirmed in the case of Venture, East of Sable Island).*

3. Data collection procedure

The data from both dates were collected with sonobuoys, air-deployed and monitored from a Maritime Patrol Aircraft (MPA) deployed by 14-Wing Greenwood, Nova Scotia.

On the 27-May sortie, the aircraft deployed only one sonobuoy at each site, a directional SSQ-53D(2), and remained on site for approximately 2 hours. The MPA monitored the four sonobuoys concurrently. Because of the distance between the Sable Bank and Gully sites, the RF link occasionally degraded, leading to short periods of low data quality. An air-deployed expendable bathythermograph (AXBT) was deployed at each site for an estimate of the temperature/sound-speed profile in the water. Local shipping was not monitored by radar on this flight.

On the 2-December sortie, the aircraft followed a procedure similar to that described in [4]. At each of the three sites (Sable N, Gully S, and LC), acoustic sensors were placed at the apices of an equilateral triangle with 10 nautical mile sides as shown in Fig. 2 (where a, b and c are the North, East and West apex respectively). At each apex of the triangle, a set of sensors consisting of one 53D(2) sonobuoy, one 525 sonobuoy and one 57B sonobuoy were deployed. A description of each sensor is included in Table 2. The use of three sensors at each apex ensured the redundancy required to detect unserviceable buoys and/or problems with the data stream. All sonobuoys were deployed at a nominal depth of 30 metres. Data were recorded for approximately 1 hour at each site.

During the 2-December sortie, an AXBT was also deployed at the apex a of each site. The aircraft radar was used for a shipping survey in a 50-75 nautical mile radius centred on the site. Weather data were obtained by direct observation from the aircraft.

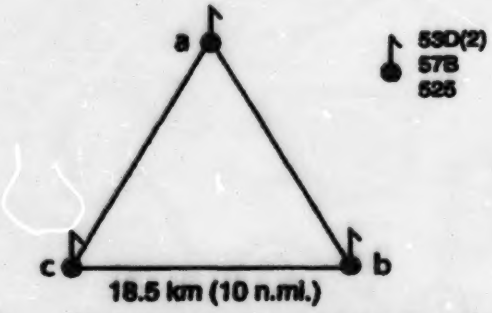

Figure 2: Sensor deployment at the Sable N, Gully S, and LC sites.

Table 2. Acoustic sensor description.

NAME	SENSOR TYPE	BANDWIDTH
AQS-53D(2)	Omnidirectional and horizontal directivity	10-2000 Hz
AQS-57B	Omnidirectional	10 Hz - 40 kHz
AQS-525	Omnidirectional and limited vertical directivity	10-2000 Hz

4. Data processing

4.1 First stage manipulation

The analog acoustic data from the sonobuoys were transmitted by radio to the MPA, and written at 7.5 in./s on a 28-track magnetic tape using the onboard analog tape recorder. These tapes were played back in the laboratory, passed through anti-aliasing filters with a cut-off frequency of 3277 Hz (2 Dec) or 1638 Hz (27 May), sampled at twice the cut-off frequency, and recorded onto digital linear tapes (DLTs).

Auto-power spectra (for all buoys) and cross-power spectra (for the directional buoys) were then calculated using averaging times of 30 seconds and 300 seconds (5 minutes). Fast Fourier transforms (4096-point and 8192-point transforms for the 27-May and the 2-December data sets, respectively) were used with a Hanning window to produce 0.8-Hz spectral estimates. The 30-second spectral estimates were displayed in a frequency-time intensity greyscale format to assess the data quality. Further processing was done on the 300-second spectral estimates, using only those periods that passed the data quality tests. The selected 300-second spectra were averaged over one-third octave bands from 20 to 1000 Hz.

Calibration files, for each buoy-type except the 57Bs, were obtained from sonobuoy calibration trials previously conducted at DREA. SSQ-57B sonobuoys are individually calibrated in production. Sonobuoy specifications call for an acoustic sensitivity across the band of interest of +/-3 dB for 53D(2) and +/- 2 dB for the 57B [5].

4.2 Omnidirectional processing

For the 2-December sites, a representative sensor was chosen from each set of sensors by comparing spectral data from each of the individual sensors. Where possible, 53D(2) were picked.

In order to assess variability, the mean and standard deviation of the noise levels were calculated for the three local collection points at each site. Spatial fluctuations $F_{Spatial}$ were defined as the standard deviations (σ) between the mean noise levels from each of the apices of the triangular collection pattern. This statistic represents the expected fluctuation for the site over a spatial scale of about ten nautical miles.

$$F_{Spatial} = \sigma(\overline{N_a}, \overline{N_b}, \overline{N_c}) \qquad (1)$$

The temporal fluctuations, $F_{Temporal}$, are defined, for each set of spectral data, as the standard deviation of the noise field over the hour. In order to obtain a temporal fluctuation statistic for each site, the mean of the temporal fluctuations from each of the apices is calculated.

$$F_{Temporal} = \frac{1}{3}\sum_{\{a,b,c\}}\sigma_i \qquad (2)$$

Thus, spatial fluctuations are the standard deviations of the mean noise at each apex; whereas, temporal fluctuations are the average of the noise standard deviations at each apex.

For the 27-May sites, the omnidirectional channels of the 53D(2) sonobuoys were used to produce a mean omnidirectional noise spectrum for each site. The temporal fluctuations were the standard deviations of the noise spectra over the period of data collection. The spatial fluctuations could not be calculated, as there was only one buoy per site.

4.3 Directional processing

The directional buoys have three channels: one omnidirectional and two directional. All three channels were calibrated using a standard calibration file for the 53D(2) sonobuoy. In addition, the directional channels were calibrated by another factor to atone for added gains in the data acquisition system, assuming 2-D isotropic noise. The factor was either 2.2 or 2.3 dB re $1\mu Pa^2/Hz$, as determined for each data set individually by investigating the on-axis sensitivity of the directional channels as compared to the sensitivity of the omnidirectional channel using the one-third octave frequency band centered on 316 Hz. After the calibration procedure, the data from the directional buoys were beamformed with a limaçon beamformer to create 8 coarse beams equispaced in azimuth. A magnetic compass aligns one of the directional channels to magnetic north, so the magnetic declination of each drop site (given in Table 3) was used to reference the beams to true North. Thus, the beam directions were north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), and northwest (NW).

Table 3. Magnetic declinations for the 1998 sites.

SITE DESCRIPTOR	MAGNETIC DECLINATION
Gully N	20°28'W
Sable S2	20°07'W
Sable S1	20°10'W
Gully SE	20°10'W
Sable N	20°17'W
Gully S	20°22'W
LC	21°10'W

Slightly over an hour's data was processed, yielding around 13 sequential 5-minute time samples for each data set. However, bad samples (e.g., due to loss of RF link or buoy self-

noise) were discarded, so individual data sets could have fewer time samples. For example, the worst case was the SE Gully directional buoy which only had 6 usable time samples. The power spectral estimates for each beam were combined to form spectral levels averaged over one-third octave frequency bands (50 to 250 Hz) for each good time sample. The one-third octave frequency bands were calculated from 50 to 250 Hz, not 20 to 1000 Hz like the omnidirectional buoys, because below 50 Hz, 53D(2) can be self-noise limited, while above 400 Hz, the directional sensors can employ an in-band resonance. Means and standard deviations for the ambient noise spectrum levels were computed for each beam in the frequency bands of interest.

4.4 Data quality assessment

The 30-second spectral estimates were displayed in frequency-time intensity greyscale format to assess data quality. Visual inspection of the spectrograms showed periods when rapid changes occurred to background noise levels due to RF interference or loss of the data stream. Non-functioning buoys were also identified from the grams. Other sources of noise, such as the overflying MPA or suspicious short-scale broadband noises were also identified. A careful analysis of the spectra was made to identify potentially bad records, affected by very low-frequency self-noise or other malfunctions.

Tables 4-7 provide lists of identified bad records for each omnidirectional buoy, and the three channels for the directional 53D(2) buoys. In the final analysis, each 5-minute record containing one of the bad time segments was eliminated.

Table 4. Bad records for Sable N (total of 144 30-second records)

APEX	BUOY TYPE	CHANNEL	BAD RECORDS
a	53D(2)	3	1-5
		19	1-5
		35	1-5
	57B	12	1-5, 2 broadband noise around 54 and 95 (real)
	525A	9	1-4
b	53D(2)	11	1-12
		27	1-12, 14, 18, 22, 77 (noise affects 20 Hz only)
		43	1-12, 14, 18, 77 (noise affects 20 Hz only)
	57B	5	1-12, 18 at VLF
	525A	2	unserviceable
c	53D(2)	4	1-18, 28 at VLF
		20	1-18
		36	1-18
	57B	6	1-19 – sonobuoy is noise limited
	525A	10	1-18

Table 5. Bad records for Gully S (total of 153 30-second records)

APEX	BUOY TYPE	CHANNEL	BAD RECORDS
a	53D(2)	3	1-5, 148-153, 46-47 are high at VLF
		19	1-5, 148-153, 46-47 are high broadband
		35	1-5, 148-153, 46-47 are high broadband
	57B	12	1-37, 148-153
	525A	9	9-32, 148-153. Probably not good, levels too low
		16	unserviceable
b	53D(2)	11	1-15, 148-153, 44-46 are high
		27	1-15, 148-153, 16-46 are noisy (delete)
		43	1-15, 148-153, 16-46 are noisy (delete)
	57B	5	1-18, 148-153
	525A	2	1-12, 148-153
c	53D(2)	4	1-10,16,17, 36, 37, 112, 113, 133, 141, 142, 147-153
		20	1-9, 16, 17, 148-153
		36	1-10, 16, 17, 36, 37, 147-153
	57B	6	1-9, 36, 37, 148-153, 58-63 (noisy)
	525A	10	1-44, 148-153

Table 6. Bad records for LC (total of 149 30-second records)

APEX	BUOY TYPE	CHANNEL	BAD RECORDS
a	53D(2)	4	1-40
		20	1-41
		36	1-40
	57B	6	1-40
	525A	10	1-40
b	53D(2)	11	1-20, 38, 39, 53 (MPA)
		27	1-20, 39, 40, 53 (MPA)
		43	1-20, 39, 40, 53 (MPA)
	57B	5	1-20, 39, 40, 41 (noisy from 21-38)
	525A	2	unserviceable
c	53D(2)	3	1-8, 40
		19	1-8, 54
		35	1-8
	57B	12	1-42
	525A	9	1-12, 40, 141-149

Table 7. Bad records for 27-day sites (total of 240 30-second records)

SITE	BUOY TYPE	CHANNEL	BAD RECORDS
Gully N	53D(2)	3	0-12, 22, 30-33, 48, 117-142, 175-239
		19	0-12, 22, 30-33, 48, 117-142, 175-239
		35	0-12, 22, 30-33, 48, 117-142, 175-239
Sable S2	53D(2)	4	0-62, 166, 188, 190-193, 197-239
		20	0-62, 166, 193, 198-239
		36	0-62, 166, 193, 198-239
Sable S1	53D(2)	11	0-65, 187-190, 198-239
		27	0-65, 187-190, 198-239
		43	0-66, 186-239
Gully SE	53D(2)	12	0-89, 140-141, 166-239
		28	0-89, 140-141, 166-239
		44	0-89, 140-141, 166-239

5. Environmental information

Estimates of wind speed and direction, sea state (Beaufort scale), and significant wave height were obtained from the aircrew for each 2-December site, and are listed in Table 8. The quantities, in particular significant wave height, are difficult to estimate from an aircraft and have a large margin of error. No precipitation was observed at any of the sites. On 27-May, the aircrew did not record environmental information; however, wind estimates (at 12 UTC, for the four sites) were provided by the Meteorological Service of Canada [6]. Thus, the 27-May estimates in Table 8 are based on sustained wind speeds (i.e., an hourly average) at a nominal height of 20 metres. The wind speeds in brackets are the estimated wind speed at 10 metres, which is the standard height normally used in the literature. The wind speed and direction values were estimated using information from archived weather maps, Sable Island, and ships in the area.

For all flights, water temperature profiles were estimated from air-deployed expendable bathythermograph (AXBT) records. These profiles are shown in Fig. 3. An AXBT survey was done to the south of the sites on 27 May 1998. The profile shown in Fig. 3 for that date is from the AXBT nearest to all sites.

A shipping survey was completed during the December sortie. No ships were observed in a 50 to 75 nautical mile radius around the Laurentian Channel site. Eleven ships were sighted in the vicinity of the Gully/Sable sites, depicted by crosses in Fig. 4.

The oil wells in the Gully/Sable area are listed in Table 9. Seismic surveys were in progress in May 1998, we have reports that no activities occurred on 27 May [7].

Table 8. Wind speed and direction, sea state and significant wave height at each site.

DATE	SITE DESCRIPTOR	WIND DIRECTION (TRUE	WIND SPEED (KNOTS)	SEA STATE (BEAUFORT)	SIG. WAVE HEIGHT (M)
27 May 1998	Gully N	300	30 (28)	—	—
27 May 1998	Sable S2	290	20 (18.5)	—	—
27 May 1998	Sable S1	300	30 (28)	—	—
27 May 1998	Gully SE	300	30 (28)	—	—
2 December 1998	Sable N a, b and c	280	35	3-4	5-6
2 December 1998	Gully S a, b and c	280	40	4	4-5
2 December 1998	LC a, b and c	277	34	5	7

Table 9. Oil well information from [3]. "A" indicates active wells, "NA" indicates non-active wells.

WELL NAME	FIELD	(NAD83)	(NAD83)	SPUD DATE	27-MAY-98	2-DEC-98
THEBAUD 5	THEBAUD	43.891214	-60.199222	16-Dec-98	NA	NA
THEBAUD 3	THEBAUD	43 891214	-60.199222	22-Nov-98	NA	A
THEBAUD 4	THEBAUD	43 891214	-60.199222	20-Nov-98	NA	A
THEBAUD 2	THEBAUD	43.891214	-60.199222	18-Nov-98	NA	A
THEBAUD 1	THEBAUD	43.891214	-60.199222	15-Nov-98	NA	A
PANUKE PP3C J-99	DEEP PANUKE	43.808494	-60.732797	17-Jul-98	NA	NA ?
VENTURE 1	VENTURE	44 033333	-59 581667	20-Jun-98	NA	A ?
VENTURE 3	VENTURE	44.033333	-59 581667	18-Jun-98	NA	A ?
VENTURE 4	VENTURE	44.033333	-59.581667	16-Jun-98	NA	NA
VENTURE 5	VENTURE	44.033258	-59 581808	14-Jun-98	NA	NA
VENTURE 2	VENTURE	44 033397	-59 581719	12-Jun-98	NA	NA
GRAND PRE G-08		43 956889	-60 507111	4-May-98	A	NA
PANUKE PP3B J-99	PANUKE	43 80849	-60.732795	29-Apr-98	A	NA
PANUKE PP3A J-99	PANUKE	43 80849	-60 732795	15-Mar-98	NA	NA

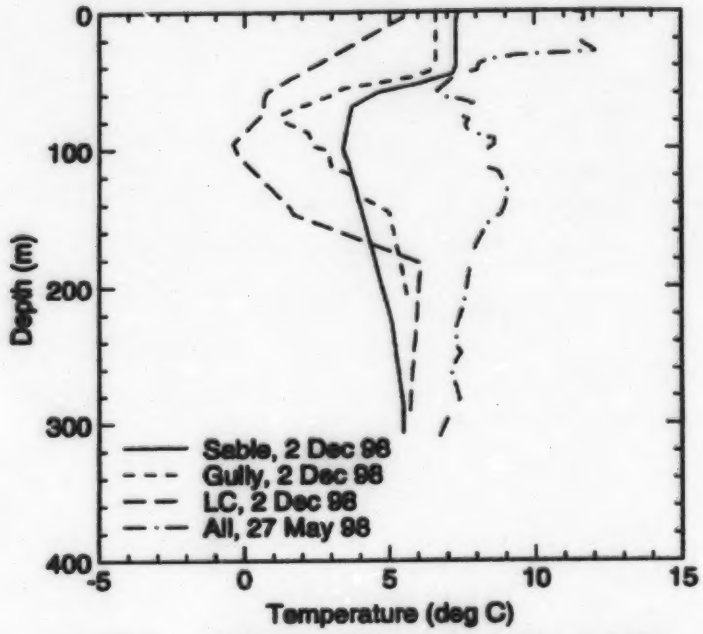

Figure 3: Water temperature profiles at/near each site.

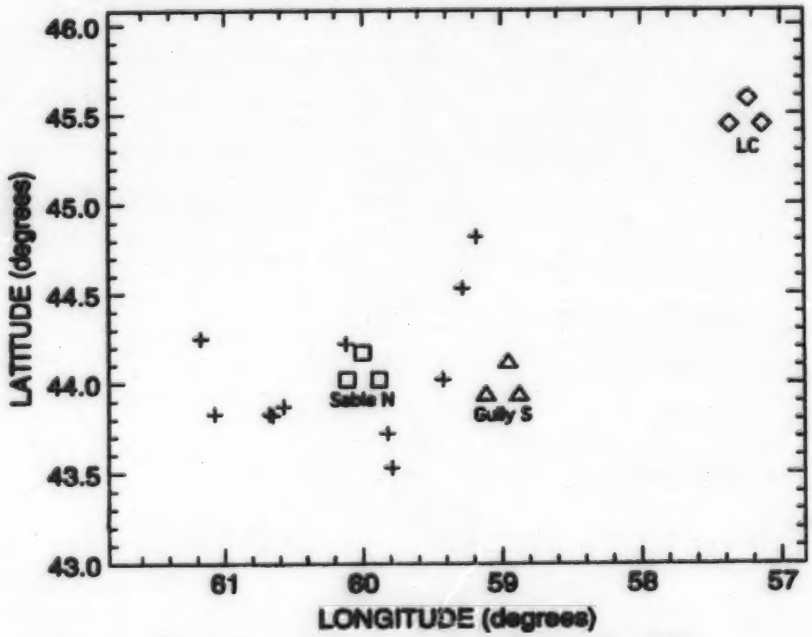

Figure 4: Shipping survey for 2 December 1998.

6. Omnidirectional noise data

The results from the statistical analysis are shown in Tables 10 to 12 for the three sites in December 1998. Each table contains the following values for the eighteen one-third octave frequency bands centered between 20 and 1000 Hz:

- the mean noise levels and standard deviations (σ) observed at each apex of the three sites for the representative buoy selected;
- the overall mean noise level at each site; and
- the temporal and spatial fluctuations at each site.

Table 13 contains similar omnidirectional information for the four sites from the 27-May flight. In this case, however, the mean noise levels are those of the only buoy at each site, and the temporal fluctuations are represented by the standard deviations. No spatial fluctuations were available for these flights, since only one buoy was deployed at each site.

Table 10. Mean noise levels (dB re 1μPa²/Hz) and standard deviations (dB) for the representative buoy of each apex at Sable N.

FREQUENCY	APEX A		APEX B		APEX C		OVERALL	FLUCTUATIONS	
(HZ)	MEAN	σ	MEAN	σ	MEAN	σ	MEAN	TEMPORAL	SPATIAL
20	109 4	1 79	108.0	1 18	104.3	1.16	106 5	1 37	2.11
25.1	112 1	2.76	103.1	1.98	104 6	3.00	106 6	2.58	3.94
31.6	112.1	2.91	104.0	2.20	108.0	2.13	107.4	2.41	3.42
39.8	114 9	3.70	108.8	2.89	108 5	2.08	110.1	2.89	3.49
50.1	118 5	3.16	109 7	3.73	113 0	3 44	113 7	3.45	3 6
63.1	111.3	3.44	103.3	3 37	107.4	3.33	107 3	3.38	3.23
79 4	101 6	2 07	93 8	2.03	94 9	2 32	98.7	2.14	3.48
100	91.4	2 02	88 4	0.90	89 8	1.18	89.9	1.37	1 25
125 9	92 7	2 21	87.7	1.01	90 1	1.70	90 1	1.84	2.03
158 5	90 0	2 20	85 9	0 78	88 4	1 58	88 1	1.52	1 71
199 5	87 5	1 90	84 7	0 71	85.8	0.68	86 0	1 1	1 18
251 2	86 3	1.35	83.9	0.37	85 0	0.47	85.1	0 73	0 95
316 2	85 6	1 14	83.7	0.34	84 8	0 38	84.7	0 61	0 76
398 1	84 7	0 63	83 4	0.29	84 2	0 31	84 1	0 41	0.54
501 2	84 8	0.49	83 9	0.22	84 5	0.27	84.4	0 33	0.39
631	84 7	0 38	84.0	0.22	84 7	0.31	84 5	0 31	0 34
794 3	84 0	0.28	83.4	0 24	84 2	0.33	83 9	0 29	0.31

Table 11. Mean noise levels (dB re 1μPa²/Hz) and standard deviations (dB) for the representative buoy of each apex at Gully S.

FREQUENCY	APEX A		APEX B		APEX C		OVERALL	FLUCTUATIONS	
(HZ)	MEAN	σ	MEAN	σ	MEAN	σ	MEAN	TEMPORAL	SPATIAL
20	100 9	1.67	100 7	1.04	119.5	3.32	107 0	2.01	8 84
25.1	94.5	0.99	93 1	0.66	106.6	4.38	96.7	2.06	7.01
31 6	95.6	2.94	93.7	3.27	92.9	0.56	94 1	2.26	1 11
39 8	95.9	2 94	94 8	3.59	93 7	0.97	94.8	2.5	0 66
50 1	90 9	1 81	90.7	1 71	91 8	0.55	91.1	1 36	0 51
63 1	88 9	1.04	89.1	1 34	91 8	1.57	89.9	1.32	1.32
79.4	86 2	0 72	85.6	0 76	89 0	0 77	87.0	0 75	1.48
100	85 2	0 42	83.8	0.29	87 7	0 45	85.6	0 39	1.65
125 9	85 0	0.43	83.4	0 42	87 5	1.15	85.3	0.57	1.66
158 5	84 4	0.34	82.9	0 40	86 2	0.65	84.5	0 46	1.36
199 5	83 6	0.33	82 2	0 37	84 8	0 32	83 5	0 34	1.07
251 2	83 7	0.30	82.4	0 40	84 6	0 36	83.6	0.36	0 9
316 2	83 6	0.28	82.4	0 48	84 2	0 44	83.4	0 4	0 76
398 1	83 4	0.28	82.2	0 48	83 5	0 34	83 0	0.37	0 6
501 2	83 6	0.28	82.5	0 49	83.5	0.36	83.2	0 38	0.47
631	83 6	0.27	82.6	0.52	83.2	0.38	83 1	0 39	0.42
794 3	82.9	0.31	81.7	0.56	82.5	0.40	82.4	0 42	0.47
1000	81 6	0 32	80.1	0.57	81.5	0 42	81.1	0 43	0 67

Table 12. Mean noise levels (dB re 1μPa²/Hz) and standard deviations (dB) for the representative buoy of each apex at LC.

FREQUENCY	APEX A		APEX B		APEX C		OVERALL	FLUCTUATIONS	
(HZ)	MEAN	σ	MEAN	σ	MEAN	σ	MEAN	TEMPORAL	SPATIAL
20	108.0	0.53	103.2	0.75	104.5	0.94	104 6	0 74	1 13
25 1	98.0	0 48	96.6	0.42	97.2	0.67	97.3	0 59	0.57
31 6	93.5	0.20	93.8	0.18	93 6	0.60	93.7	0.39	0.12
39.8	93 1	0 42	92.6	0.20	92 7	0.79	92.8	0.47	0 22
50 1	94.0	0.65	92 2	0.24	92 7	0.60	93.0	0.5	0.74
63.1	94.5	0.59	92.2	0.72	94 3	1.03	93.7	0.78	1 06
79.4	95 6	1.23	93.4	1.33	95 6	2.02	94 9	1.53	1 04
100	90.1	0.42	88.8	0.19	89.4	0.55	89.4	0 39	0.55
125 9	88 1	0.25	87.6	0.16	87.8	0.14	87.9	0 18	0.22
158.5	86 4	0 11	86 3	0 13	86 5	0 16	86.4	0.13	0.09
199.5	85.2	0.09	85 1	0 13	85 4	0.23	85 2	0.15	0 1
251.2	85 0	0 13	84.9	0.10	85 1	0.18	85.0	0.14	0 09
316.2	84 7	0.10	84.5	0.13	84.8	0.15	84.7	0.13	0 11
398 1	84.1	0.15	83.9	0 11	84 2	0 18	84.1	0.15	0.14
501 2	84 1	0 15	83 9	0.14	84.2	0 19	84.1	0 16	0.12
631	83.9	0.16	83 7	0 15	83 9	0.18	83 9	0 16	0 09
794 3	82 9	0 18	83.0	0.14	83 0	0.18	83.0	0.17	0 04
1000	81.3	0 21	81 8	0 19	81 6	0.20	81 6	0 2	0 2

Table 13. Mean noise levels (dB re 1μPa²/Hz) and standard deviations (dB) for the 4 buoys of the 27-May flight.

FREQUENCY (HZ)	GULLY N		SABLE S2		SABLE S1		GULLY SE	
	MEAN	σ	MEAN	σ	MEAN	σ	MEAN	σ
20	84 8	3.77	78 3	2.55	87 4	2 38	83.5	1.47
25 1	81 4	4.27	80 6	1.50	87.1	1 66	90.0	0.84
31 6	79.2	3.50	80.8	0.95	86.9	1.28	91.7	1.16
39.8	77.6	2.73	79.8	0.82	87.2	0.93	91.4	1.55
50.1	76.2	2.15	79.5	0 66	86.7	0.67	89 9	1.89
63 1	76 8	1.42	76.7	0.92	83.3	0.99	83.3	1.11
79 4	72.4	1 55	75 8	0.78	84 7	0.71	76.5	0.55
100	70 1	1.41	74 5	1 07	82 0	0 75	71.3	0 77
125.9	69 8	0 92	74 8	1 01	81.6	0.92	68 8	0 97
158 5	69 0	0.70	73.8	1.18	83.2	0 97	66.8	0.75
199 5	68 3	0 53	72.0	1.16	81.7	0 91	65.2	0.99
251 2	68.6	0 34	72 2	0 79	81.3	0 60	64 5	0.91
316 2	68 8	0.24	72.0	0 75	81.9	0.61	64 0	0.83
398 1	68 8	0 18	69 7	0.43	80 2	0 83	63 7	1 26
501.2	69 1	0 11	67.2	0.57	78.1	0.59	64 3	1 79
631	69 0	0.11	65.9	0.48	74.5	0 87	64.0	1.69
794 3	68 3	0 08	64.7	0.33	74.1	1.17	63 0	1 46
1000	68.8	0.11	63 0	0 39	71.9	1 51	61 9	1.55

Different noise mechanisms are responsible for the noise levels across the frequency bands examined [8]. Shipping traffic usually dominates the noise for frequencies from 10 to 100 Hz. A significant contribution can arise from distant shipping if the environmental conditions are favorable to long-range propagation. Above 100-200 Hz, wind-excited noise (or sea surface agitation) is typically more important, with high wind speeds corresponding to higher background noise levels. At approximately 20 Hz, finback whales contribute significantly to the noise levels of the eastern continental shelf. These mammals are vocally active in the vicinity of the Scotian Shelf during mating season [9, 10]. They have been shown to greatly influence the noise levels near 20-Hz during the winter months on part of the Scotian Shelf [4].

To investigate the relative importance of these noise contributors, the seven sites have been separated into 3 general areas: the Gully, Sable Bank, and the Laurentian Channel (see Fig. 1 for clarification). The mean omnidirectional noise levels will be investigated for these three areas, followed by the temporal and spatial fluctuations.

6.1 The Gully: Mean noise levels

The mean noise levels for the three Gully sites are shown in Fig. 5. The data from Gully S (solid line) were collected in December, while the data from Gully N (dotted line) and SE (dashed line) were collected in May.

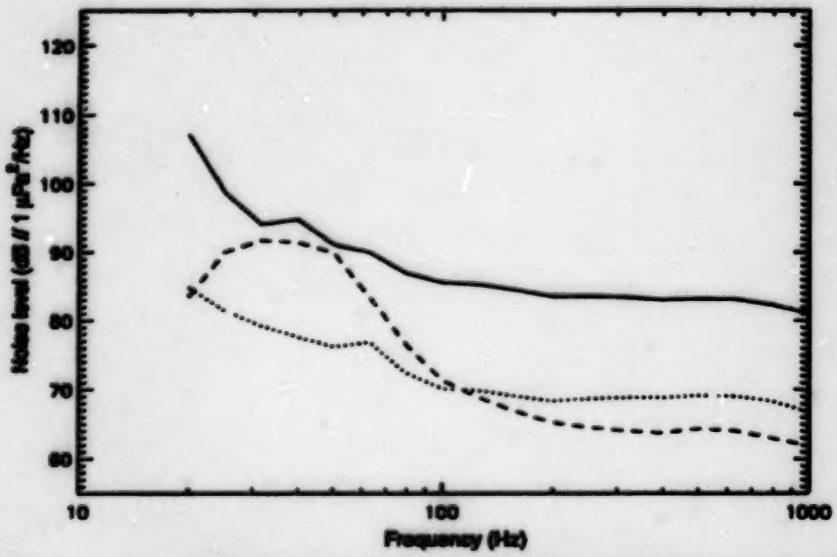

Figure 5: Mean noise levels (one-third octave bands) for Gully S (solid line), Gully N (dotted line), and Gully SE (dashed line).

The noise levels above 100 Hz are significantly higher at Gully S than at Gully N and SE, and agree with the wind data of Table 8. At Gully S, the quoted wind speed (in Table 8) is 40 knots for a sea state of 4 to 5. A higher sea state is normally associated with 40-knot winds, which could indicate that the winds had not been strong for an extended period of time. The observed noise levels at 1000 Hz (wind-noise dominated band) were approximately 81 dB re $1\mu Pa^2/Hz$ for Gully S (see Table 11), which is within 2 dB re $1\mu Pa^2/Hz$ of the 33-knot average levels measured by Piggott at that frequency [11]. Piggott is the main reference for background wind noise levels on the Scotian Shelf. Other studies for the Scotian Shelf and Grand Banks [12, 13] (covering larger areas and periods) have all agreed closely with Piggott's measurements, unless the data were contaminated by shipping noise. At Gully N

and SE, the wind speed was approximately 30 knots, and the mean 1000-Hz noise levels were closer to 65 dB re 1μPa^2/Hz (67 and 62 respectively, see Table 13). These levels correspond to wind speeds of 10 knots on Piggott's scale. The difference can probably be attributed to an inaccuracy of the sustained wind speed estimates from archived data, as these estimates could be too high. From 200 to 1000 Hz, the levels at Gully SE are 2-5 dB lower than those of Gully N, but the archived wind data give the same wind speeds for the two sites. This apparent discrepancy agrees with other observations that noise levels at deep-water sites are typically approximately 5 dB lower than in shallow water, as reported by Wenz [8].

At 20 Hz, the noise levels at Gully S are approximately 20 dB higher than those of Gully N and SE, indicating significant fin whale activity in December. The analysis of the individual buoys for Gully S showed that the levels for the frequency band centered on 20 Hz were 10 dB higher than the levels of adjacent frequency bands for apices a and b of the triangular buoy pattern. At apex c, the levels were more than 20 dB higher than those at 32 Hz (see Fig. 6). This variation is a strong indication of the presence of finback whales west of the deployment site. A small increase (less than 5 dB re 1μPa^2/Hz) is occasionally seen at 20 Hz for the Gully N site, which may have been caused by the presence of whales, although it is not for certain. The presence of finback whales near the Scotian Shelf area is a documented occurrence, and they have been routinely detected acoustically. The 20-Hz levels were shown to follow a yearly cycle with a peak between the mating months of October and January [4].

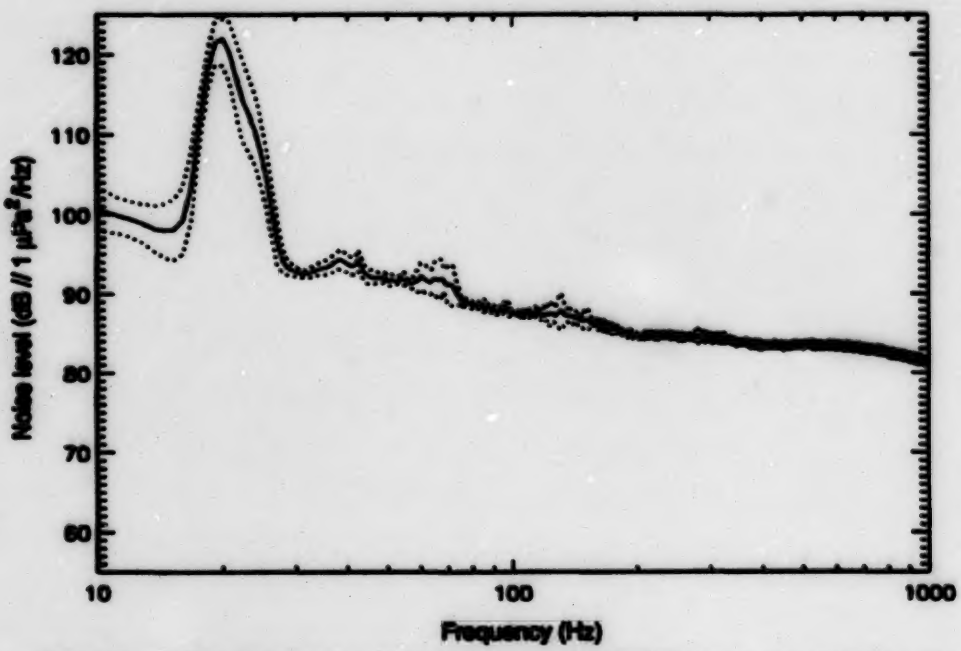

Figure 6: Average spectrum (solid line) for the 53D(2) buoy located at Gully S c. The dotted lines represent the mean spectrum ± the estimated standard deviation.

Noise levels in the 10 to 100/200 Hz band depend largely on shipping traffic and propagation conditions in the area. A significant contribution can arise from distant shipping if the environmental conditions are favorable for long-range propagation.

At shipping frequencies (20-100 Hz), the levels are higher at Gully S and SE, as shown in Fig. 5. The observed levels of 90-95 dB re 1μPa^2/Hz in the 40-60 Hz band are representative of a high shipping density according to the Wenz curves for shallow water [8]. The shipping survey at the Gully S site indicated eleven ships within 50 to 75 nautical miles of the site (shown in Fig. 4), which explains the high noise levels. Although no shipping information is available for the May flight, the levels at Gully N are nearly 15 dB lower than those of Gully S at shipping frequencies, and correspond to usual shipping noise levels for shallow water [8]. Gully SE displays levels closer to those of Gully S. Since Gully SE is in deeper waters, however, a significant contribution is presumed to be from long-range shipping noise from the deep ocean.

6.2 The Sable Bank: Mean noise levels

The mean noise levels for the three Sable Bank sites are shown in Fig. 7. The data from Sable N (dashed line) were collected in December, while the data from Sable S1 (solid line) and S2 (dotted line) were collected in May.

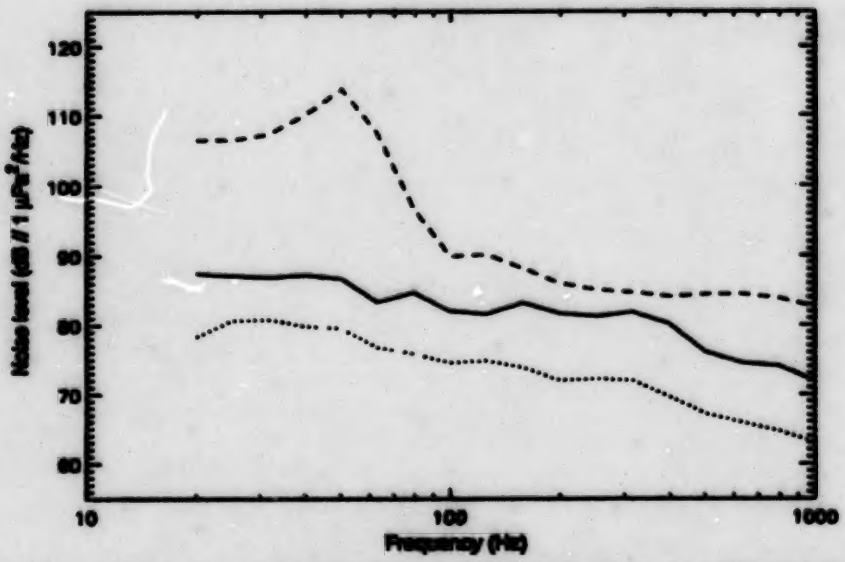

Figure 7: Mean noise levels (one-third octave bands) for Sable S1 (solid line), Sable S2 (dotted line), and Sable N (dashed line).

According to the shipping survey, eleven ships surrounded the Sable N site, as shown in Fig. 4. The mean noise levels between 30 and 100 Hz for Sable N (in Fig. 7) indicate a high level of shipping traffic, with the levels being slightly higher than those from Gully S (in Fig. 5). These slightly higher levels correspond to the distribution of ships being predominantly closer to Sable N than to Gully S in Fig. 4. At Sable N, noise levels in excess of 100 dB re 1μPa^2/Hz were measured in the same band, with a peak at 118 dB re 1μPa^2/Hz for apex a of this site. These levels are among the highest ever measured on the Scotian Shelf, according to various surveys [13, 4, 12]. Levels in the order of 105 dB re 1μPa^2/Hz (at 50 Hz) were measured on Western Bank in December of 1995, with five ships in the area [2]. In the past, these high levels have been explained by the presence of the nearby shipping lane to Halifax, and with the high density of shipping from the survey, this explanation again applies here. Since the highest levels were measured at Sable N a (North apex), the apex furthest away from the active wells, drilling activity appears to be a lesser contributor to the noise field on that date.

Although no shipping information was available for the May flight, the data from Sable S1 were visibly corrupted by a nearby ship. The spectrogram for that buoy showed several well-defined narrowband lines, as well as broadband patterns indicative of a CPA (closest point of approach) path to the buoy. The fine spectral structure for the Sable S2 buoy showed similar features (although at lower levels) to the Sable S1 buoy, including matching CW tones. We therefore conclude that the broadband noise levels measured at the Sable S1 were heavily contaminated by nearby shipping noise. Without this influence, it is expected that the levels would have been closer to those of Sable S2. The 20-200 Hz levels for Sable S2 are representative of levels for a medium shipping area [8].

At wind-driven frequencies (above ~200 Hz), the levels of Sable S1 were due in part to the close-by ship, although the wind speed was also estimated at 30 knots. The mean levels at Sable S2 were 63 dB re 1μPa^2/Hz at 1000 Hz (see Table 13) and correspond to wind speeds of 10 knots on Piggott's scale. The estimated wind speed was closer to 20 knots, but again, this estimate is based on archived information, and as such, could be highly variable. At Sable N, the levels were approximately 84-85 dB re 1μPa^2/Hz, and within 3 dB re 1μPa^2/Hz of Piggott's average levels for the observed wind speed of 33 knots.

High noise levels in the 20-Hz band were observed at Sable N, indicating the likely presence of finback whales in the area. The 20-Hz levels were 20-25 dB less at the sites surveyed in May (Sable S1 and S2).

6.3 The Laurentian Channel: Mean noise levels

The mean noise levels for the Laurentian Channel site are shown in Fig. 8.

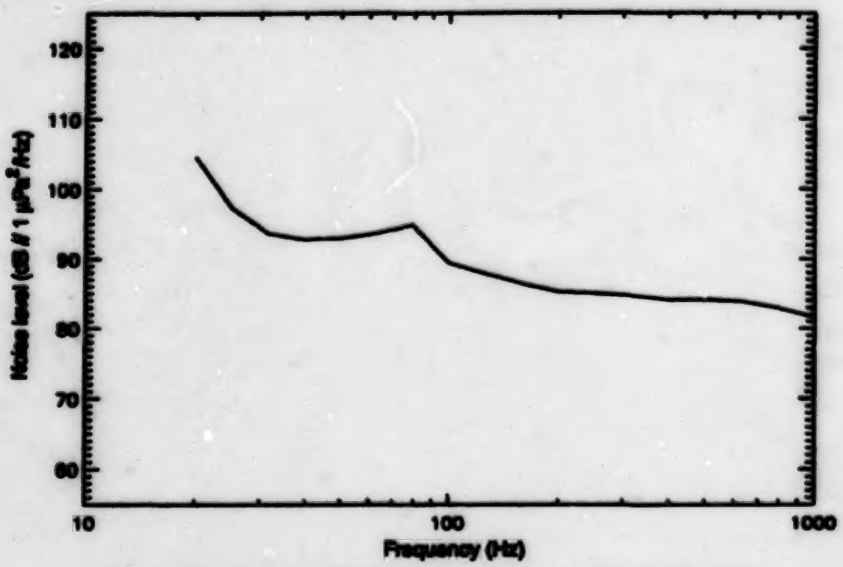

Figure 8: Mean noise level (one-third octave bands) for LC.

The data from all three apices of this site were very similar to one another, showing very little variation. The main features at this site are the 10-dB increase of the noise levels at 20 Hz (compared to those at 30 Hz) due to finback whales, and the approximately 95-dB re $1\mu Pa^2/Hz$ peak at 80 Hz due to shipping.

It is interesting that the shipping noise is limited in bandwidth, with little structure observed outside of the 60-80 Hz band. The radar survey indicates that no ships were located within a 75 nautical miles radius around the site. The shipping noise therefore comes from long-range shipping, presumably from the deep-water area North or South of the site (in line with the Laurentian Channel). Acoustic propagation through the channel effectively filters out the low-frequency component of the shipping noise.

The observed noise levels at 1000 Hz (wind-noise dominated band) were 81.6 dB re $1\mu Pa^2/Hz$ for the Laurentian Channel (Table 12), which is within 3 dB re $1\mu Pa^2/Hz$ of the 33-knot average levels measured by Piggott at that frequency [11].

6.4 Short-term (<1 hour) temporal fluctuations

The temporal fluctuations of the noise levels are mostly due to shipping traffic (mainly close-range traffic) and changes in weather conditions. Across the spectrum, high temporal fluctuations are linked to periods of overall low noise levels, i.e., when the signal-to-noise ratio of short-term noise sources is stronger. Fluctuations found in the literature usually refer to fluctuations at one sensor (as opposed to cross-sensor comparisons), and therefore should compare to our temporal fluctuations rather than the spatial fluctuations presented in the following sub-section. Figures 9 to 11 show the temporal fluctuations for the Gully, the Sable Bank, and the Laurentian Channel, respectively.

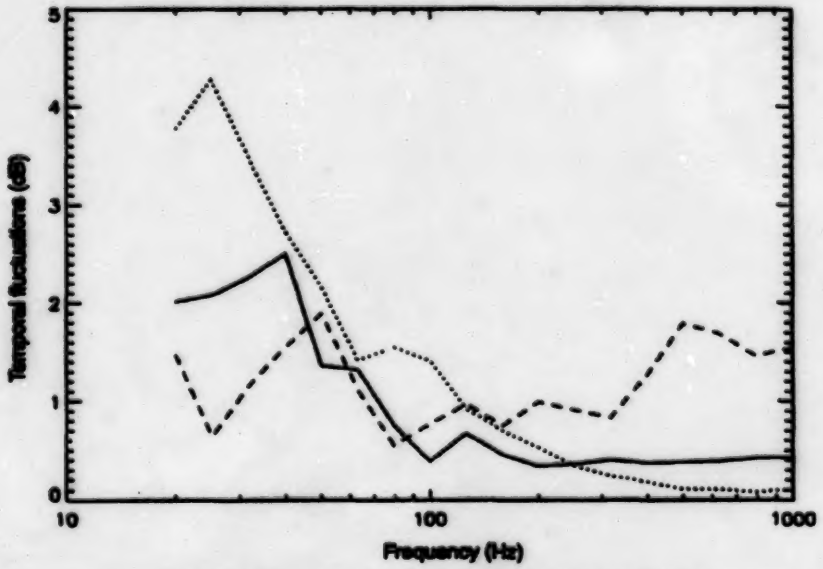

Figure 9: Temporal fluctuations for the Gully: Gully S (solid line), Gully N (dotted line), and Gully SE (dashed line).

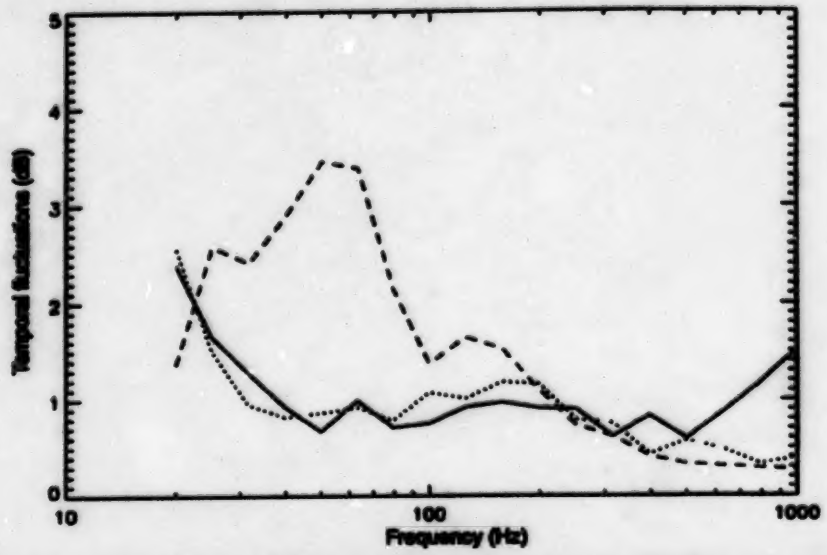

Figure 10: Temporal fluctuations for the Sable Bank: Sable S1 (solid line), Sable S2 (dotted line), and Sable N (dashed line).

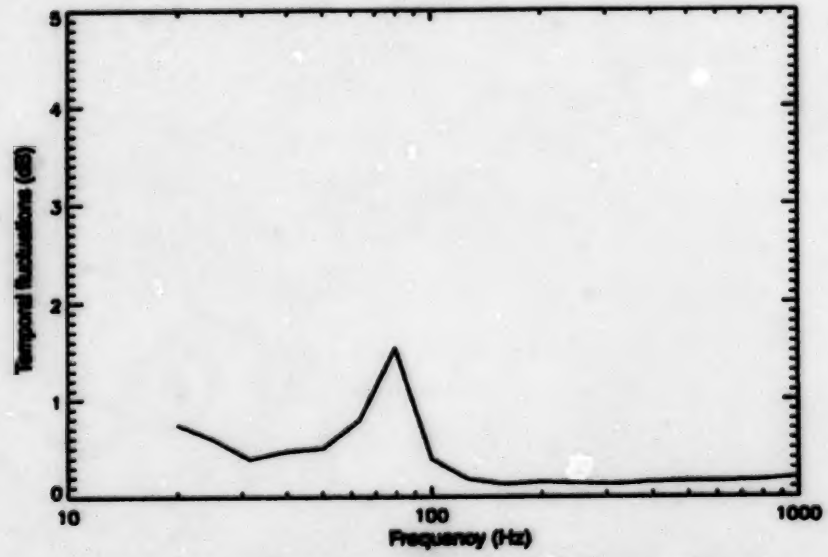

Figure 11: Temporal fluctuations for the Laurentian Channel.

At higher frequencies (above 200-300 Hz), temporal fluctuations are low, typically less than 1.5 dB re 1μPa^2/Hz at all sites. These fluctuations are within the envelope of fluctuations

measured at other sites on the Scotian Shelf throughout 1996 [13]. The Gully SE site (in Fig. 9) displayed higher fluctuations than all of the other sites, but it also had the lowest noise levels at these frequencies, as shown in Fig. 5. The gram for the Gully SE buoy showed higher levels at high frequency for a period of time, and insufficient information is available to pinpoint the source of the noise. The high frequency fluctuations for the Sable S1 site in Fig. 10, however, are an artifact from the nearby ship affecting the background noise levels.

At shipping frequencies (25-100 Hz), temporal fluctuations are higher than those at high frequencies (>200 Hz), but on average less than 3 dB. Both Zakarauskas *et al.* [12], and Desharnais *et al.* [13] also found higher standard deviations at shipping frequencies in the order of 1-3 dB and 4-5 dB, respectively. Temporal fluctuations larger than 3 dB re $1\mu Pa^2/Hz$ are generally attributed to the passage of ships past the sonobuoy field at relatively close range. Both ship noise levels (Fig. 7) and temporal fluctuations (Fig. 10) were highest at Sable N, in accordance with the short-range shipping traffic from the shipping survey (Fig. 4). Shipping was also high at the Gully S site (Fig. 4), and at Sable S1 where one ship was closing on the buoy. In the case of Sable S1, however, ship noise was consistently high throughout the period, leading to overall low fluctuations.

A small yet consistent increase was seen in the temporal fluctuations below 30-40 Hz. The temporal fluctuations reported in Desharnais *et al.* [13] followed a similar trend. The particularly high fluctuations below 40 Hz for the Gully N site (in Fig. 9) is believed to be an artifact of system noise for this particular buoy. The sites where the finback whales were suspected (Sable N, Gully S and LC) do not display particularly large fluctuations at 20 Hz. This lack of fluctuations is due to the regular distribution of the whale calls during the measurement periods (several calls are typically present during each 5-min period, and therefore are not seen as a fluctuation from one 5-min period to the next). Some categories of ships (e.g., large tankers) have a large impact on low-frequency temporal fluctuations, such as those measured at Sable S1 and S2 (Fig. 10). This effect is strongest when the range to the ship changes during the measurement period.

6.5 Spatial fluctuations

In the same manner as temporal fluctuations, high spatial fluctuations are usually observed in overall low noise levels, when the signal-to-noise ratios of potential sources are stronger. The observed spatial fluctuations were mostly due to shipping traffic (mainly close-range traffic), and the presence of finback whales (around 20 Hz). Figure 12 shows the spatial fluctuations for the 2-December sites.

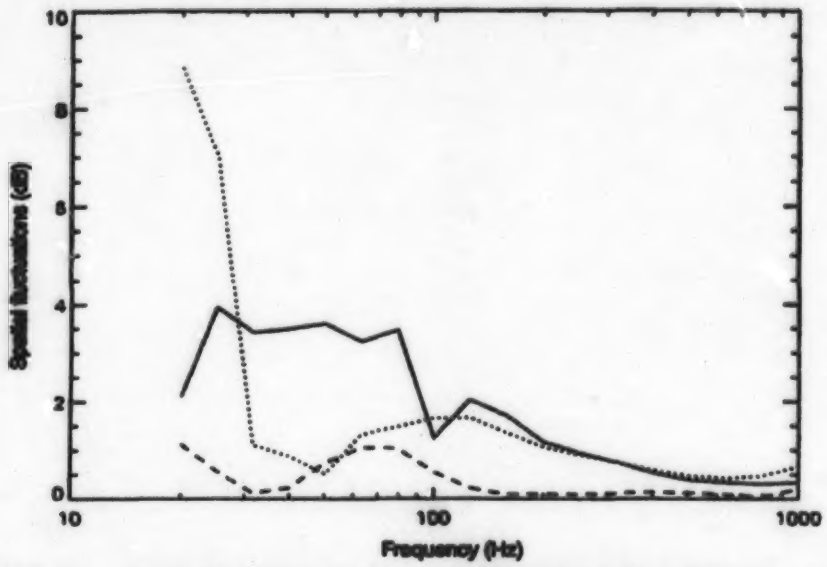

Figure 12: Spatial fluctuations for the 2-December sites: Sable N (solid line), Gully S (dotted line), and LC (dashed line).

At high frequencies (above 200-300 Hz), the spatial fluctuations on the Scotian Shelf were less than 2 dB, as shown Fig. 12. Similar fluctuations were reported in [13], except for cases with extremely low wind speeds and calm seas. At shipping frequencies, the highest fluctuations were measured at the Sable N site, as expected since this site had the highest shipping traffic. These higher fluctuations indicate an anisotropy in the shipping distribution around the sonobuoy field, which is illustrated by the shipping survey in Fig. 4.

The 20-Hz fluctuations at Gully S (dotted line in Fig. 12) are amongst the highest ever documented on the Scotian Shelf (8 dB was reported in [13] on Grand Banks in the winter time). This site also displayed 20 Hz levels of 20 dB or more above those at 30 Hz, and the levels at Gully Sc are 20 dB higher at 20 Hz than those at Gully Sa and Sb. These facts indicate that the whale(s) was very close to Gully Sc. This is not unrealistic considering the documented presence of fin whales on the Scotian Shelf in the winter months [10].

7. Directional noise data

The 8 beam outputs for each of the 13 buoys were analyzed to determine beam directions with the maximum and minimum ambient noise spectrum levels in one-third octave frequency bands centered at 63 and 200 Hz, respectively. These results are shown in Fig. 13, where the beam direction is a function of the percentage of occurrence of the maximum level (depicted by solid lines with diamonds) or minimum level (depicted by dotted lines with triangles). In addition, results from a similar study, using 138 buoys in the Sable Gully area from Dec 1995 to Dec 1996, are provided (in red) for comparison [14]. For both data sets, at either 63 or 200 Hz, the beams with the highest noise levels point consistently in a northerly direction (N and NE). This result indicates that noise sources with the highest levels (e.g., shipping, and fishing activities) exist in a northerly direction from the drop sites. The beams with minimum levels point in a mainly southerly direction.

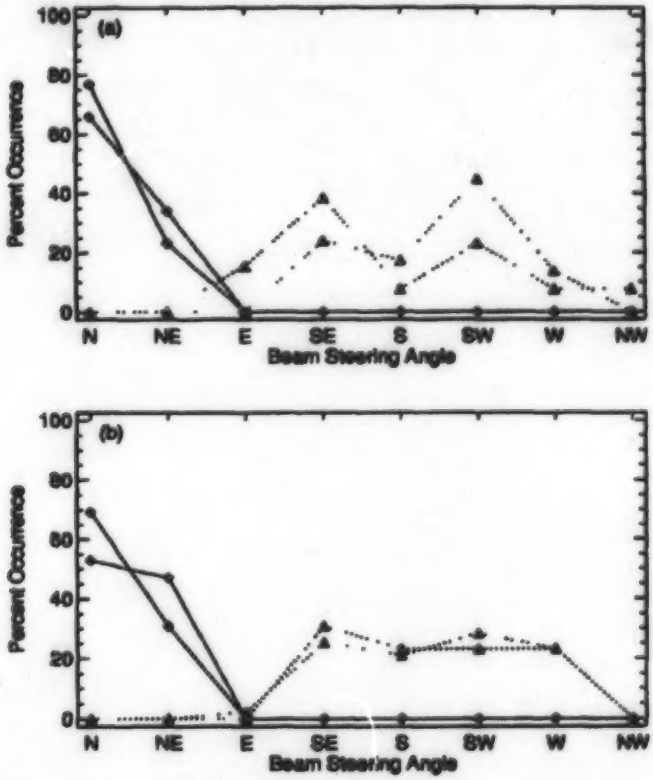

Figure 13: Beam direction as a function of percent occurrence of maximum (solid lines) or minimum (dotted lines) noise levels for one-third octave frequency bands centered on (a) 63 Hz and (b) 200 Hz. The black lines denote percentages using the 13 buoys from the May and Dec. 1998 data, while the red lines provide a comparison of percentages from a similar study using 138 buoys from Dec. 1995 to Dec 1996.

8. The new data in its context

There are a few available data sets describing the ambient noise levels in the areas of interest [2, 11, 12, 13]. Desharnais *et al.* [2] compiled data from these references and other unpublished data sets for the Sable Bank area. Figure 14 groups Fig. 1 and 2 of [2] and shows the ambient noise levels versus frequency for Sable Bank (solid lines and small dots with overlaid standard deviations). The data sets introduced in this report (Figs. 5, 7 and 8) are included in Fig. 14 as large filled and unfilled squares, circles, diamonds, and upward and downward triangles.

Since the new data sets are reasonably close to one another, the general levels were expected to fit within the levels from [2]. Figure 14 points out some important differences. At wind-dominated frequencies (above ~200 Hz), the levels from the 27 May 98 sites all fit within the levels from [2]. The sites surveyed on the 2 Dec 98 show higher levels, up to 8 dB above all other data sets at 1000 Hz. The wind speed of 35-40 knots measured on the 2 Dec 1998, however, was significantly higher than the maximum wind speed of all other measurements which was 20 to 25 knots. Since the levels of the 2 Dec 98 data sets are all within 3 dB re $1\mu Pa^2/Hz$ of one another and fit within the predicted levels for the wind speed (based on the Piggott model), these levels can be used to redefine the envelope of noise levels to be expected above 200 Hz on Sable Bank, including the surrounding area of the Gully. This fact potentially changes the interpretation from [2] where the higher levels to the NE (for a site to the SW of Sable Island) had been associated with drilling activities on Sable Bank. The two new data sets show stronger noise levels to the N/NE, independent of the well locations.

The levels at shipping frequencies (20-200 Hz) mostly fit within the levels of the previous measurements, with the exception of Gully N and Sable S2 (with levels lower by 2-5 dB), and Sable N (with levels approximately 10 dB above). Since Gully N is at the eastern edge of the Gully, it is possible that a change in sediment type triggers higher losses and lower background noise levels for this area. Also, the shipping noise from Sable Bank may not effectively reach the eastern side of the Gully. We cannot answer this question without a larger data set.

In the case of Sable N, the difference in noise levels at shipping frequencies is important, and may indicate a significant difference between the levels near Sable Island and those further off the Island. Since the directionality of the noise field indicated higher levels in the N/NE direction, the high levels at this site are probably not due to activities at the drilling sites, or their supply vessels, on these dates.

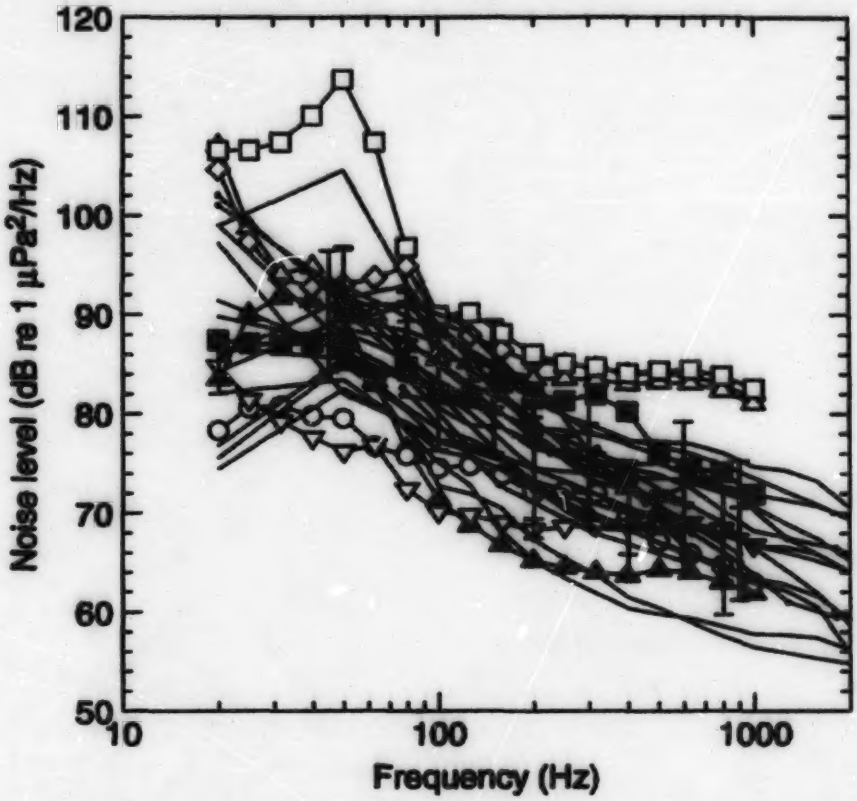

Figure 14. Overview of the range of ambient noise levels versus frequency from [2]. The solid lines and small dots with overlaid standard deviations represents the range of measurements obtained from the EC-SWAN data set [2]; the large filled and unfilled squares, circles, diamonds, upward and downward triangles represent the data sets introduced in Figs. 5, 7 and 8.

At 20 Hz, the levels from 27 May 98 fit well within the levels of the previous data sets (Fig. 14). The levels from 2 Dec 1998, however, are approximately 5 dB re 1µPa^2/Hz higher than previously reported [4]. Nonetheless, these new levels are consistent with the previous levels if background noise levels are taken into account. In the previous data sets, when fin whales were presumed to be in the area, the levels at 20 Hz were typically about 10 dB higher than the levels at 30 Hz, unless shipping noise was high (above 100 dB re 1µPa^2/Hz), in which case the levels at 20 Hz were similar to those at 30 Hz. We observe a similar 10 dB increment at 20 Hz for the Gully S and Laurentian Channel sites, though no relative increase is noted at the Sable N site (where shipping noise is important) with noise levels of 107 dB re 1µPa^2/Hz at 30 Hz. It is possible that the fin whales try to achieve a given signal-to-noise (SNR) ratio in their vocalizations, and that the achieved SNR would be lower in noisy conditions.

The DREA data collection was searched for other data sets applying to the Laurentian Channel. We found two sources reporting data for the Channel: at a deep-water site [15] and Cabot Strait [16]. These data are reproduced in Fig. 15 (small dots joined by solid lines), along with the Laurentian Channel data from Fig. 8. We find that the new data are 4 to 13 dB higher than the past data, depending on the frequency band. Differences are due to higher wind speeds for the new data sets, and the presence of finback whales. Since the past Laurentian Channel data sets fit well within the envelope of values for Sable Bank/Gully area, it is expected that Fig. 14 could successfully be used to characterize the range of noise levels that can be expected within the Laurentian Channel. This conclusion cannot be confirmed without a larger data set for the area, covering a wider range of seasons and weather/shipping conditions.

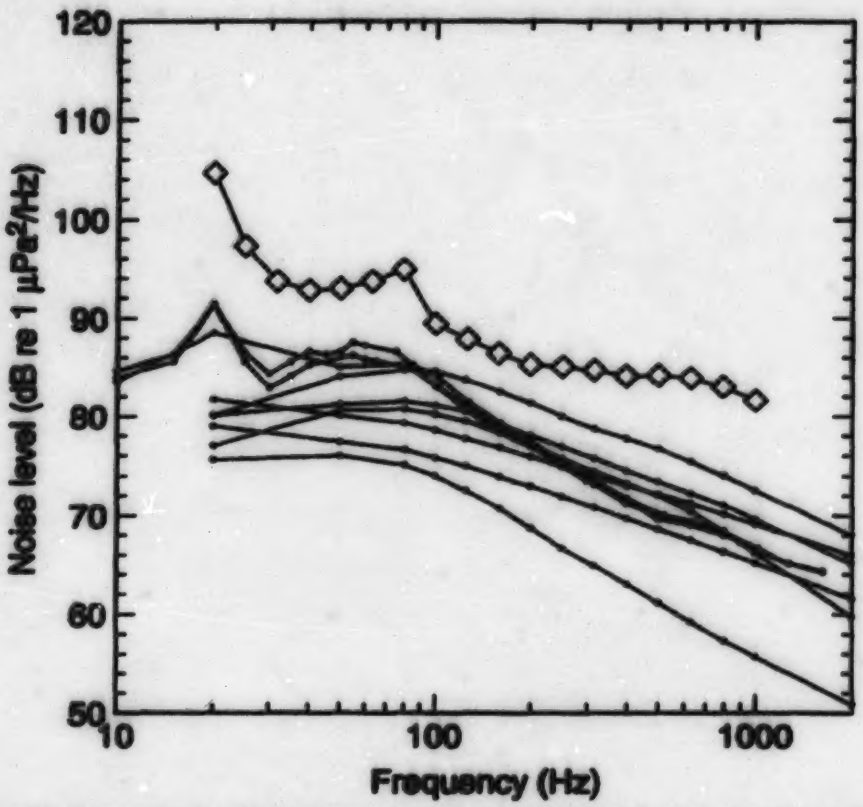

Figure 16. The solid lines and small dots represents the measurements from [15] and [16]; the diamonds represent the data from Fig. 8.

9. Summary

We found that the new data sets presented here for the Sable Bank/Gully area fit well with previously published levels for Sable Bank. The envelope of expected noise levels have been slightly increased by the higher wind speeds observed during the new data sets. Figure 14 characterizes the range of noise levels that can be expected in the area. Though the data sets are more limited for the Laurentian Channel, the values for that area also fit well within the envelope of Fig. 14.

The directionality of the noise field showed a small increase in the noise levels in the north or northeast direction. This directionality had been observed in the past for several sites on the Scotian Shelf, Grand Banks area [4]. An analysis of the noise field at a site located to the SW of Sable Island [1] had previously argued that the increase to the NE may have been caused by the oil wells near Sable Island. In the frequency range of 50 to 250 Hz, the oil wells did not influence the background noise field on Sable Bank on either date.

References

1. Heard, G.J., Desharnais, F., Hazen, M. and Fraser, I., "Sable Bank Ambient Noise," Contractor Report prepared for LGL Environmental Research Associates, February 1999.

2. Desharnais, F, Heard, G.J., Hazen, M.G. and Fraser, I.A., "The underwater acoustic noise field on Sable Bank, Canadian Acoustics, v.27, no. 3, September 1999, pp. 30-31.

3. Moir, P.N., Geological Survey of Canada (Atlantic), Personal communication.

4. M.G. Hazen and F. Desharnais, "The Eastern Canada Shallow Water Ambient Noise Experiment," Proc. of IEEE Oceans '97, Vol. 1, 471-476 (1997).

5. "Production Sonobuoy Specification for Bathythermograph transmitting set AN/SSQ-36A and 36B and Sonobuoy AN/SSQ-53D, 53E, 57B, 62C, 77B and 86," NAWC FSC 5845, 26 Oct. 1994.

6. Richards, W., Atlantic Climate Centre, Meteorological Service of Canada, Personal communication.

7. Personal communication between the Canada Nova Scotia Offshore Petroleum Board and Maj. Mark Labrecque, Defence Research Establishment Atlantic.

8. G.M. Wenz, "Acoustic Ambient Noise in the Ocean: Spectra and Sources," J. Acoust. Soc. Am. 34, 1936-1956 (1962).

9. W.A. Watkins, P. Tyack, K.E. Moore and J.E. Bird, "The 20-Hz Signals of Finback Whales (Balaenoptera physalus)," J. Acoust. Soc. Am. 82, 1901-1912 (1987).

10. S.K. Katona, V. Rough and D.T. Richardson, *A field guide to whales, porpoises, and seals from Cape Cod to Newfoundland*, 4th edition, p. 36 (Smithsonian Institution Press, Washington, 1993).

11. C.L. Piggott, "Ambient Sea Noise at Low Frequencies in Shallow Water of the Scotian Shelf," J. Acoust. Soc. Am. 36, 2152-2163 (1964).

12. P. Zakarauskas, D.M.F. Chapman and P.R. Staal, "Underwater Acoustic Ambient Noise Levels on the Eastern Canada Continental Shelf," J. Acoust. Soc. Am. 87, 2064-2071 (1990).

13. Desharnais, F. and M.G. Hazen, "Fluctuations of underwater acoustic ambient noise levels on the Eastern Canadian continental shelf," submitted to J. Acoust. Soc. Am., 2001.

14. Franklin, J.B., "Ambient noise measurements on the Canadian continental shelf," DREA Contractor report 97/411, 1997.

15. Adlington, R.H., "Measurement of ambient ocean noise with the Remote Acoustic Data Acquisition System," DREA Research Note SWA/84-2, 1984.

16. Collier, A.J., "The effect of ice cover on shallow water ambient noise, J. Acoust. Soc. Am. 53, p.353[a], (1973).

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)

Defence Research Establishment Atlantic
PO Box 1012
Dartmouth, Nova Scotia, Canada B2Y 3Z7

2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable)

UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title)

Background noise levels in the area of the Gully, Laurentian Channel, and Sable Bank

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

Francine Desharnais and Nicole E. B. Collison

5. DATE OF PUBLICATION (month and year of publication of document)

April 2001

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc)

46

6b. NO. OF REFS (total cited in document)

16

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered)

EXTERNAL CLIENT REPORT

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include address)

Department of Fisheries and Oceans

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)

9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)

DREA ECR 2001-028

10b. OTHER DOCUMENT NOs. (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
( ) Defence departments and defence contractors; further distribution only as approved
( ) Defence departments and Canadian defence contractors; further distribution only as approved
( ) Government departments and agencies; further distribution only as approved
( ) Defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected)

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM
UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

The Sable Gully is a submarine canyon at the edge of the continental shelf, east of Sable Island. This region is a potential Maritime Protected Area (MPA) under the Oceans Act. New data sets in the area of Sable Bank, Sable Gully and Laurentian Channel were analyzed to characterize the current ambient noise field in these areas. It was found that the new data sets fit reasonably well with previously published levels for Sable Bank. The directionality of the noise field showed a small increase in the noise levels in the north or northeast direction. This directionality agrees with a previous analysis of several sites on the Scotian Shelf and Grand Banks area.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

UNCLASSIFIED
SECURITY CLASSIFICATION OF FORM